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OPTICAL LOCATION OF THE MOON*

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(Presented by Academician D. V. Skobel'tsyn,
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Physics Institute of the AS USSR, 28 Sept. 1963

One of the possible regions of application of lasers is in ranging and location [1]. In this article the authors describe the preliminary results of location of the moon with the aid of a ruby laser. /1303

Description of the apparatus. Fig. 1 shows the apparatus in schematic form. A single telescope, mirror diameter D = 2.6 meters [2], was used for both transmitting and receiving the light pulses. The transmitting-receiving apparatus was mounted in the coudé focus (focal length F = 104 meters) and hence remained fixed when the telescope was rotated. The ruby laser was designed by V. S. Zuyev and P. M. Kryukov and has the following parameters: wavelength $\lambda = 6943$ Å, pulse energy $W_p = 50 - 70$ joules, pulse length $\tau_p = 2$ milliseconds, beam diameter $d = 11$ mm, beam divergence $\alpha = 3'$.

The lens L_1 with a focal length f = 32 cm is adjustable. It is easy to show that the beam divergence on leaving the telescope is $\alpha_1 = \alpha \frac{f}{F} \leq 0.5''$. This corresponds to a circular patch on the moon of diameter $d_M \leq 0.7$ km (neglecting the broadening of the beam in the atmosphere).

Taking into account the scattering of the light during its

[redacted]

double journey through the atmosphere and possible mismatching of the apertures of the apparatus in the transmitting and receiving regimes, the angular field of view of the receiving apparatus was taken as $\alpha_2 = 8''$, which corresponds to a circular patch on the moon of diameter $d_M = 14$ km. The diameter of the receiving diaphragm in the focal plane of the telescope, corresponding to $\alpha_2 = 8''$, is $d_D = 4$ mm.

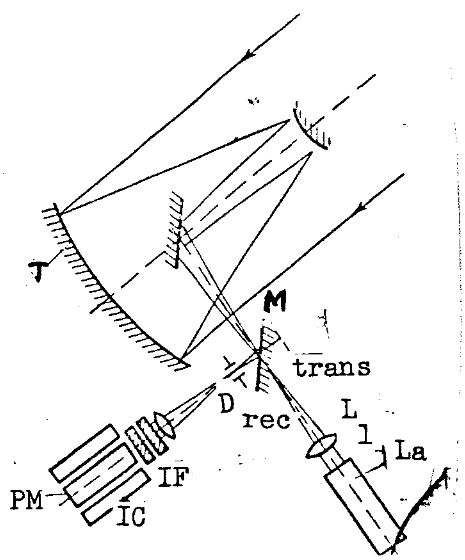

Fig. 1. Schematic representation of apparatus used in the optical location of the moon:

T - telescope, La - laser, L_1 - matching lens, M - pivoted mirror, D - diaphragm, IF - interference filter, PM - photomultiplier, IC - container for dry ice.

To register the reflected signal we used a photomultiplier. To reduce the dark current this was cooled with dry ice (- 76°). At this temperature its parameters were: quantum efficiency $k_{PM} = 0.04 - 0.05$; dark current $n_{PM} = 50$ photoelectrons per second.

In order to reduce background noise a 6943 Å interference filter with an absorption coefficient at this wavelength $k_f = 0.5$ and a transmission band $\Delta\lambda = 20$ Å was placed in front of the photocathode. The apparatus was switched from the transmitting to the receiving regime by means of a mirror M, capable of assuming two positions.

After shaping and amplification, the signal from the photomultiplier output was registered by means of an oscillograph with a 6-millisecond slave sweep. A special device triggered the oscillograph sweep with a delay corresponding to the calculated time for the signal to travel to the moon and back.

<u>Preliminary estimate of signal-to-noise ratio</u>. The energy of the light pulse reflected from the moon can be estimated on the basis of the relation /1304

$$W_{ref} = W_{or} \frac{S_T}{\pi R^2} \rho k_1 k_2 k^2_{atm}, \qquad (1)$$

W_{ref} = energy of reflected signal per unit area on earth, W_{or} = energy of original signal, S_T = surface area of receiving apparatus, R = = 384,000 km = distance to the moon, $\rho = 0.1$ = lunar albedo, k_1, k_2 = = loss factors of transmitting and receiving apparatus respectively, k_{atm} = loss factor in atmosphere. For average zenith angles k_{atm} is usually 0.8. Relation (1) holds true if it is assumed that the circular patch of light fits entirely within the lunar disc and that the lunar surface reflects light in accordance with Lambert's law.

For our apparatus $S_T = 6.76$ m^2, $k_1 = 0.75$, and $k_2 = 0.35$ (it is assumed that at each reflecting or refracting surface the signal losses amount to 5 %). Then, from relation (1), we have:

$$W_{ref} = 2.2 \cdot 10^{-19} W_{or}.$$

If we assume that $W_{or} = 50$ joules, which for the laser wavelength 6943 Å corresponds to $N_{or} = 1.8 \cdot 10^{20}$ photons, the reflected signal will contain $N_{ref} = 40$ photons, or, converted to the number of photoelectrons at the photomultiplier output, $n_{ref} = 1.6 - 2.0$ photoelectrons.

Thus, reliable registration of the signal is possible only by statistical accumulation, the more so in that the background is registered together with the useful signal. There are several background sources: the dark current of the photomultiplier, the earthshine on the moon, the light of the crescent, scattered in the atmosphere and in the telescope, the night airglow. Comparative calculations showed that the principal background sources are the light of the crescent scattered by the atmosphere $n_{sl} = (4 \div 40) \cdot 10^{+2}\ \text{sec}^{-1}$ and the earthshine $n_{al} = 5 \cdot 10^{2}\ \text{sec}^{-1}$ (in numbers of photoelectrons at the photomultiplier output). The total background, referred to a time interval $\tau_{P} = 2$ milliseconds, equal to the pulse length, is:

$$n_{b} = 2 - 10.$$

Hence the expected signal-to-noise ratio

$$\frac{n_{ref}}{n_{b}} = 0.16 - 1.0.$$

<u>Results of measurements</u>. The measurements were made on 13 September 1963 between 0400 and 0532 hours. The chosen target was the

crater Albategnius on the dark part of the moon.

The triggering of the oscillograph sweep was timed so that the beginning of the reflected pulse coincided with the center of the sweep. /1305
In these circumstances the first half of the sweep (3 milliseconds) could be used for measuring the background, and the second for measuring background and signal. Moreover, in order to determine the background more accurately, it was also measured over a 10-second period a few seconds after the registration of each reflected pulse.

Altogether, 30 pulses were emitted. Thus, the accumulated signal time was $30\ \tau_P = 60$ milliseconds. The number of photoelectrons per pulse ($\tau_P = 2$ milliseconds), averaged over this time, in the sweep interval corresponding to the reflected signal is $n_{b+s} = 6.2$. The corresponding background, determined for the 10-second intervals, is $n_b = 4.67 \pm 0.38$ (RMS error). The background determined from the first half of the sweep (3 milliseconds) coincides with this value correct to the above RMS error.

The amount by which n_{b+s} exceeds n_b, namely the value of the signal $n_s = n_{b+s} - n_b = 1.53$, is four times greater than the RMS error in measuring the background, and therefore can not be ascribed to background fluctuations.

Thus, our measurements permitted reliable registration of signals reflected from the moon.

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